Role of Direct Reduced Iron Fines in Nitrogen Removal from Electric Arc Furnace Steel

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Electric arc furnace steel contains about 70-120 ppm nitrogen. There is no suitable method for nitrogen removal from electric arc furnace steel up to the level desired for good quality bars and flat rolled products (30 ppm max). The existing process based on vacuum degassing can remove only up to 20% of nitrogen in steel. In the present study DRI fines have been injected into a steel bath which can drift out nitrogen in steel through production of fine CO bubbles in-situ on reaction with residual FeO in DRI fines and C in bath. For high and medium carbon steel, nitrogen got reduced to 30 ppm and 60 ppm respectively where initial nitrogen was 150 – 200 ppm in steel. Nitrogen removal also depends upon bath depth and addition level of DRI.

Key words: arc furnace, steel, nitrogen, DRI fines, injection

Introduction

The demand for clean steel with little impurities has been increasing due to stringent quality requirements. The removal of gaseous impurities to improve quality of steel is one of the most important aspects of steel making technology. Among the three gaseous components viz. nitrogen, hydrogen and oxygen, the first one draws special attention owing to the complex mechanistic process involved in denitrogenation. Although for some steels of special purposes, nitrogen is often beneficial for strengthening and grain refinement, its control is essential for plain carbon steel to get the desired mechanical properties and weldability. Solubility of nitrogen in steel is influenced by its constituents. V, Nb, Cr, Mn increase the solubility and C, Si and S decrease the same. Nitrogen solubility is approximately 450 ppm at 1600°C in carbon and low alloy steel [1]. The typical nitrogen level in EAF-steel is 70-120ppm [2]. The steel for special applications such as automotive sheet and special bar quality product requires less than 30ppm nitrogen content. Presently around 7 million t of steel is produced through EAF in India whereas total steel production in India is 35 million t. In most cases charges for EAF are sponge iron and scrap which are prone to nitrogen pick-up in comparison to hot metal charging. Therefore, EAF steel needs special attention on removal of nitrogen for production of special quality bar and flat rolled products by controlling the input of nitrogen also by adopting appropriate methodology during melting and refining.

Although exhaustive research on the nitrogen removal of steel has been done to improve the quality of steel, little work has been reported on the powder top blowing route. Revelation has been that there are two basic processes for nitrogen removal from steel:

– Through slag phase by slag/metal reaction
– Through gas phase by gas/ metal reaction

There are some fluxes (BaO, TiO_2, CaF_2 etc.) which have high affinity for nitrogen. The presence of those fluxes in the slag, containing other components (like CaO, MgO, SiO_2) can absorb nitrogen from liquid metal in form of various nitrides. In this case two mechanisms have been realized [3]: one is transport to slag, another is removal of nitride inclusions that precipitate preferentially in a homogeneous manner on slag droplets as readymade receptors.

Several investigators [4-8] have studied the removal of nitrogen by high nitride capacity slag. Although a remarkable nitrogen removal of around 40-50% is possible by the addition of nitride absorbing fluxes, it may be applicable only for some alloy steel where pick-up of alloying elements from the added flux becomes the added advantage. Otherwise, its application is restricted due to high cost of fluxes.

In gas phase nitrogen removal, the basic principle is to reduce the partial pressure of nitrogen below the equilibrium partial pressure. This is possible by vacuum degassing, inert gas purging or carbon boiling. Vacuum degassing can remove hydrogen up to about 1ppm, however, this degassing is not effective in removing nitrogen because of its lower diffusion coefficient [9] (about $5x10^{-8}$ m^2s^{-1} at 1873K) compared to that of hydrogen (about $10\text{-}7m^2s^{-1}$ at 1873K). That is why under the best conditions only about 10-30% nitrogen can be removed by vacuum treatment [10]. Several trials [10-12] have been carried out on vacuum degassing of nitrogen. Nitrogen removal through deep vacuum is possible but the rate is too slow to be accomplished within the shorter ladle refining time. Therefore, in view of decreasing tap to tap time in EAF, nitrogen removal via vacuum degassing becomes less acceptable.

Decrease in nitrogen partial pressure, lower than equilibrium pressure, is possible by inert gas purging. Although in vacuum degassing the surface of bath is exposed to a low pressure, at a depth the bath experiences the pressure exerted by the ferrostatic head. To overcome this, the gas purging from bottom of the bath is practiced [13]. These gas bubbles can provide sites for nucleation or for reaction. Only 10-20 ppm nitrogen removal was possible with Ar or CO_2 injection[14-16]. However, Bolstein et al. [17] have observed that CO_2 (bottom) stirring in BOF to be more beneficial to the nitrogen removal than Ar stirring. Bottom purging of CO_2 can reduce nitrogen by up to 30% [6]. Of course, there may be a chance of C and oxygen pick-up due to the dissociation of CO_2 gas.

Carbon boiling i.e. in-situ CO gas bubble generation inside the bath is possible by the following ways:

– DRI charging
– Oxygen blowing
– Injection of oxide fines

Jerry Thomas et al. [18] have reported that DRI charge addition of up to 50% or more can provide enough carbon and oxygen to form CO gas bubbles for removal of nitrogen up to a very low level. They also suggested that a higher amount of DRI charging may also duplicate the effect that can be accomplished via oxygen blowing. As per previous investigation by Centre for Materials Production (CMP) [18-19], it was believed that the CO from DRI was released in molten metal and played an important role in removing nitrogen from the bath. Therefore, DRI addition is more effective than carbon oxidation. However, the work proposed by CMP at North Star Steel [19] indicated that CO evolution from DRI completed rapidly (20-30 s with incubation period of 2-4 s) during melting. It is completed in the slag phase and does not extend to the metal. Hence, no remarkable carbon boiling occurs in the metal bath so that DRI addition is not so effective. The same result has been observed previously by other investigators as well [20- 21].

CO produced from the reaction of blown oxygen and bath carbon can reduce nitrogen remarkably but it is possible only in high carbon steel. For low carbon steel, if oxygen is blown, bath carbon decreases, also iron loss occurs due to the oxidation of Fe in bath.

Iron ore powder injection from top for removal of nitrogen from steel has been carried out by several investigators [2, 22]. Injected iron oxide powders disperse in the steel bath and react with bath carbon to form CO gas bubbles which are very active in purging out nitrogen from the bath. It has been observed that iron ore injection can produce more efficient carbon boiling for removal of nitrogen than oxygen blowing. But it is difficult to control due to severe foaming and slopping. In this context investigators [23] have used DRI fines/ iron carbide fines injection into the bath, considering these are the sources of FeO and C to form CO bubbles inside the bath. They have given some model equations in a large scale study and found a remarkable removal of nitrogen. However, the scope of studies on the kinetics of removal of nitrogen for different addition level, carbon content of bath and effect of other parameters e.g. inclusion level of steel, composition, yield etc are still open.

Present Study

The main objective of the present study is to investigate the role of direct reduced iron (DRI) fines in removing nitrogen from arc furnace steel. FeO (20%) and C in DRI fines and in bath react to form CO bubbles as per reaction given below [22,24],

$$FeO + [C] = Fe\ (l) + CO\ (g) \quad (1)$$

G. Brooks et. al [24] have reported that the above reaction possibly occurs at above 800°C. Therefore, at steel making temperature, CO evolution is possible from DRI. In contrast to the CMP work [18-19] the present position has been that, when DRI fines are injected into the bath with the help of Ar as a carrier gas, the fines get dispersed throughout the bath. Fine CO bubbles are formed which are very effective in drifting out nitrogen dissolved in steel. It is apprehended that foaming will be less, dissolution will be faster and yield will be more in comparison to ore fines injection. Therefore, the submerged injection of DRI fines is expected to be very effective in removal of nitrogen from steel.

DRI fines injection is more akin to nitrogen removal via gas-metal reaction, because generated CO gas is responsible for nitrogen removal. Therefore, the thermodynamics of nitrogen removal through gas-metal reaction forms the basis of the present work.

Thermodynamics. Reaction of nitrogen in steel can be represented by

$$1/2N_2\ (g) = [N] \quad (2)$$

and the ΔG_0 for the reaction is given by [25]

$$\Delta G_0 = 3598 + 23.89\ T\ (J/mol) \quad (3)$$

$$\Delta G_0 = -RT \ln K_1 \quad (4)$$

The equilibrium constant K_1 is given by

$$K_1 = a_N/p_{N2}^{1/2} = f_N\ [wt\%N]/p_{N2}^{1/2} \quad (5)$$

The activity coefficient of nitrogen in steel f_N as a function of other constituents in steel is represented by

$$\log f_N = \log\ f_N^0\ + e_N^i\ (wt\%\ i) + e_N^j\ (wt\%\ j) + ... \quad (6)$$

Since f_N^0, which is f_N at infinite dilution in binary alloy, is always 1, by definition, $\log\ f_N^0 = 0$

Hence,

$$\log f_N = e_N^i\ (wt\%\ i) + e_N^j\ (wt\%\ j) + ... \quad (7)$$

The values of K_1 at different temperatures can be calculated from equation (3) and (4). It is 0.0455 at 1600°C. In equation (5), [wt%N] is the nitrogen content of steel, i.e solubility of nitrogen at any value of partial pressure (P_{N2}). Therefore, solubility of nitrogen can be calculated from the known value of activity coefficient f_N, and P_{N2}. The values of f_N for different compositions can be calculated from equation (7) and from the respective interaction coefficient listed in **Table 1** [26].

The equilibrium partial pressure of nitrogen at 1600°C for iron of different composition is calculated from equation (5) (**Table 2**) where f_N is calculated from equation (7) and K_1 at 1600°C is calculated from equation (3) and (4). It is clear that denitrogenation of mild steel is easier compared to pure iron and stainless steel. The equilibrium partial pressure of nitrogen in stainless steel too low to remove nitrogen by gas/metal interaction. Equilibrium partial pressure of nitrogen can be reduced either by generation of vacuum or by using flushing gas. Thermodynamically both are equivalent.

Table 1. Interaction co-efficient e_i^j x 10^2 for elements dissolved in liquid iron at 1600°C [24].

Dissolved Element	Added elements												
N	C	Si	S	P	Mn	Cr	Al	V	Ni	Mo	W	Cu	O
	13	4.7	1.3	5.1	-2.0	-4.5	0.3	-10	1.0	-1.1	-0.2	0.9	55

Table 2. Calculated equilibrium partial pressure p_{N2} x 10^3 of nitrogen at 1600°C in iron melt.
1. Pure Fe
2. Fe + 0.2% C
3. Fe + 0.2% C + 0.02%S + 0.03%P + 0.3% Si + 0.3% Mn (mild steel)
4. 18-8 Stainless steel

Nitrogen Content (ppm)	Equilibrium partial pressure (atm x 10^3)			
	1	2	3	4
10	0.483	0.544	0.57	0.0175
30	4.3	4.9	5.13	.0158
60	17.3	19.6	20.5	0.632
90	38.3	44.0	46.2	1.422
120	69.55	78.45	82.0	2.529
150	108	122.57	128.0	3.952

Table 3. Chemical analysis of steel scraps and sponge iron fines used.

Songe iron fines (wt.%)			
Fe (total)	88.2	Al_2O_3	2.12
FeO	25.26	S	0.011
C	0.85		
Steel scrap (wt.%)			
C	0.29	N	0.0060
Si	0.30	O	0.0131
Mn	0.40	Fe	Bal.

Table 4. Screen analysis of DRI fines.

Size range, mesh	-60 +75	-75 +100	-100 +120	-120 +150	-150
Percentage	18	15	22	18	27

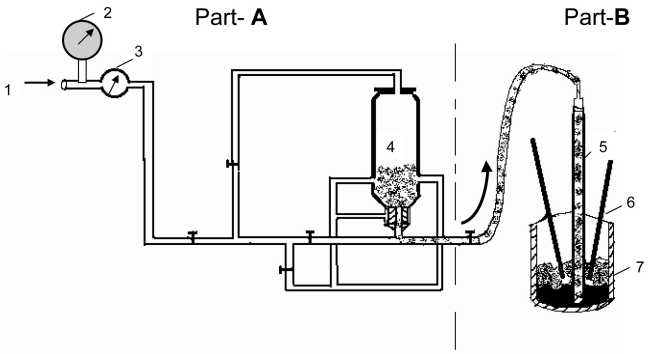

Figure 1. Schematic of experimental set-up. **Part- A.** Fluidised bed type Injector**; Part- B.** Indirect Electric Arc Furnace: 1. Argon gas from cylinder; 2. Gas regulator; 3. Flow meter; 4. Fluidised bed chamber; 5. Graphite lance; 6. Graphite electrode; 7. Furnace shell; ⊥-Valves.

Experimental

A schematic of the experimental set-up is shown in **Figure 1.** It mainly consists of injector, submerged electric arc furnace and other accessories:

Injector. It is a fluidized bed type injector. It has four inlets of gas at different points of the chamber and one outlet for fines. Ar gas from a cylinder through a rotameter (range 0.5 to 50 lpm) is passed at the flow rate of 12 lpm and 2.5 kg/cm^2 pressure. The rate of injection was controlled by the flow rate of argon gas. However, no injection was possible when the gas flow rate was down below 10 lpm. Therefore, the flow rate was maintained at 12 lpm. The capacity of the injector is 3.5 kg in a batch. Charging of fines was done by opening the top cover. The outlet of the injector was attached to a steel tube and socket with which a graphite nozzle of 50 cm length and 10 mm inner diameter was threaded.

Indirect arc furnace. This is a two-electrode indirect arc furnace of 30 kg capacity (50kVA). The furnace shell was lined with crushed magnesite bricks (-3mm size) using sodium silicate binder. Charging is done by opening the top cover. The temperature can be measured by an IR pyrometer ("ULTIMAX", range 900 – 3500°C). Injection was done through the top hole in the roof. Energy consumed, current, voltage can be observed from the panel. Metal is tapped from the furnace by tilting the shell after removal of the top cover.

Feed stock. The chemical analysis of DRI fines provided by a sponge iron plant and of the steel scraps are given in **Table 3**. DRI fines have been crushed to -60 mesh (screen analysis is given in **Table 4**).

Melting procedure. In each experiment 15 kg of steel scrap has been melted. After melting, the temperature was raised up to around 1600°C. Samples were collected through a 4mm diameter quartz tube for N, O, S and C analysis. Injection of DRI fines (-60 mesh) was continued with Ar as a carrier gas and blown for 10 minutes. Here the rate of argon flow was 12 lpm. DRI fines injection rate was 250 mg/min. The amount of DRI fines injected was measured by taking the initial and final weight of the DRI fines present in the injection chamber. Initial, final and intermediate metal samples were taken by sucking through the quartz tube. The carbon content of the bath was increased either by coke powder addition or by pig iron addition. On the other hand, to obtain a very low carbon content in steel, oxygen blowing or iron ore addition has been done. Intermediate samples were analysed for nitrogen and oxygen by

Table 5. Input material and outcome of the experiments without iron ore addition.

Expt. No	Charges kg	DRI fines injected kg	Nitrogen content ppm		Final composition of metal						Yield increased %
					ppm	wt%					
			Initial	Final	O	C	S	P	Si	Mn	
4	Steel scrap- 15 Lime- 1.5 Quartz- 0.4 C-powder- 0.5	2.5	158	33	49	1.2	0.027	0.028	0.1	0.2	14.2
5	Steel scrap- 15 Lime- 1.5 Quartz- 0.4 C-powder- 0.275	2.5	183	38	79	0.86	0.025	0.030	0.14	0.28	14
6	Steel scrap- 15 Lime- 1.5 Quartz- 0.4 C-powder- 0.2	2.5	277	70	102	0.66	0.02	0.024	0.18	0.11	14.2
7	Steel scrap- 15 Lime- 1.5 Quartz- 0.4 C-powder- 0.2	2.5	300	62	84	0.6	0.025	0.020	-	-	14
10	Steel scrap- 15 Lime- 1.5 Quartz- 0.4 C-powder- 0.2	2.5	191	69	42	0.49	0.033	-	-	-	12.6

LECO apparatus. Final samples were analysed for N, O, C and S by LECO apparatus and Si, Mn and P by conventional chemical analysis.

Results and Discussion

Injection of DRI fines was done in a molten steel bath for removal of nitrogen. The samples were analysed to quantify the nitrogen content in initial, intermediate and final steel. Initial nitrogen in steel after melt down was more than 150 ppm which appeared to be very high. In practice nitrogen in EAF steel is 70-120 ppm. This heavy pick-up may be due to very low heat size and large exposed area. However, in all the experiments nitrogen could be reduced and it was found to be dependend on several parameters as discussed below:

Bath carbon. Chemical analysis of metal samples for experiments No. 4 to 7 and 10 is shown in **Table 5**. From this table it is clear that in case of steel with a high carbon content (0.8 – 1.2%C), nitrogen removal is better than in a low carbon bath (0.5 – 0.7% C) for injection of the same amount of DRI fines in 10 minutes. When the carbon content was increased up to 1.2 wt%, the nitrogen content of steel was reduced to 33 ppm, whereas the same was around 60 – 70 ppm when the carbon content was 0.6 wt%. The curve in **Figure 2** [27] indicates that nitrogen removal is favourable at higher carbon content of the steel melt. This may be attributed to generation of CO as per equation (1). The other reason may be explained from the curves in **Figure 3**, plotted on the basis of theoretical calculation from basic thermodynamic relations as mentioned earlier [equation (2) through (7)], the activity coefficient of nitrogen in steel increases while the solubility of nitrogen in steel decreases with increase in carbon content. Therefore, a higher carbon bath facilitates scavenging of nitrogen with CO gas bubbles in the system itself.

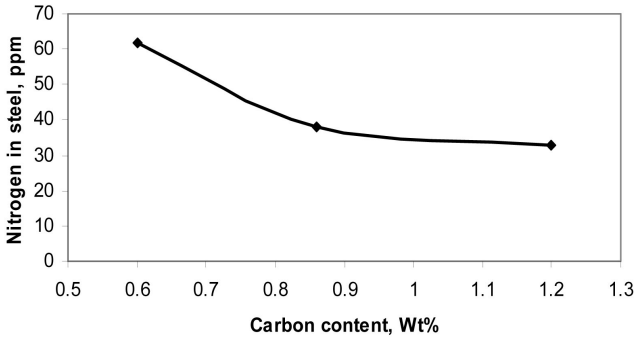

Figure 2. Carbon content versus nitrogen dissolved in steel after 2.5 kg DRI fines injection.

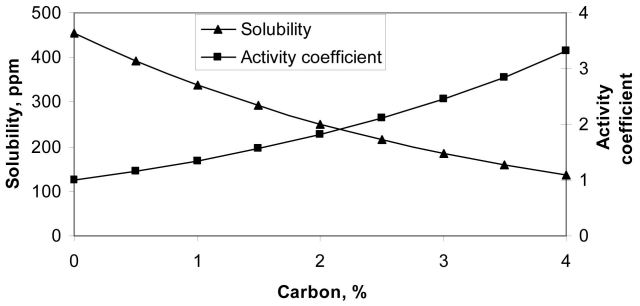

Figure 3. Solubility and activity coefficient of nitrogen in iron melt versus carbon content at 1600°C and 1 atm pressure.

From the results of the above experiments it is realized that nitrogen in low carbon steel is difficult to bring down to the desired level. Therefore, nitrogen removal in very low carbon steel was done by special technique. The carbon content of the melt was increased by adding cast iron (bal-

Table 6. Input material and outcome of the experiments with iron ore addition.

Expt. No	Charges kg	DRI fines injected kg	Iron ore added kg	Nitrogen content ppm		Final composition of metal						Yield increased %
						ppm	wt%					
				Initial	Final	O	C	S	P	Si	Mn	
11	Steel scrap- 12 Lime- 1.5 Quartz- 0.4 C. injected- 3	2.5	1.0	181	27	39	0.49	0.05	0.026	0.22	0.24	17.4
12	Steel scrap- 12 Lime- 1.5 Quartz- 0.4 C. injected- 3	1.6	1.4	140	56	89	0.34	0.02	0.039	-	-	13.6
13	Steel scrap- 13 Lime- 1.5 Quartz- 0.5 C. injected- 2	2.5	2.0	218	41	70	0.15	0.023	0.027	0.22	-	20.6

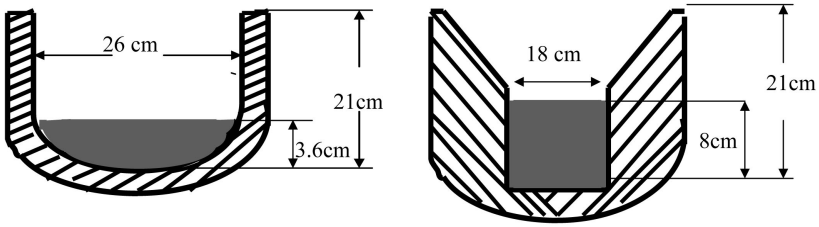

Figure 4. Schematic of EAF shell variation. (a) Conventional EAF shell. (b) Modified shell to obtain higher bad depth.

Table 7. Nitrogen levels achieved at different bath depth.

Expt. No.	Initial nitrogen, ppm	Final nitrogen, ppm
(a) Lower bath depth – U-type		
2	197	162
3	300	277
(b) Higher bath depth – Y-type		
4	158	33
5	183	38

ancing 15 kg of heat size) as shown in **Table 6.** In first two experiments the initial bath carbon was raised up to 1% and for the third experiment it was raised up to 0.8%. DRI fines were injected in this high carbon bath, thus nitrogen was reduced. At the next step the carbon content was reduced by iron ore addition. Thus, up to 27 ppm nitrogen content could be achieved. Therefore, achieving steel with the low nitrogen and low carbon content is possible by the injection of DRI fines in high carbon bath followed by removal of carbon from the bath. Though, carbon removal is also possible by blowing pure oxygen in the bath, which is normal industrial practice. In the present case, severe bath chilling has been observed in two heats during oxygen blowing. This may be due to the lower bath depth which may cause the unreacted oxygen to escape from the bath taking out a lot of sensible heat. Moreover, due to lower heat size, very high heat loss took place. Therefore, in this case iron ore was added simultaneously with arcing to reduce the carbon content of the final steel. The above technique is more favourable if scrap plus pig iron is charged or scrap plus hot metal or DRI plus hot metal rather than 100% scrap charging or 100% sponge iron charging. 100% scrap or sponge iron charged heats contain very low carbon which is not beneficial for good nitrogen removal.

Bath depth. The depth of the steel bath is an important parameter. In experiment No. 2 and 3 the bath depth was 3 cm as shown in **Figure 4a**. The initial and final (before and after injection) nitrogen content of the melt for 2.5 kg DRI fines injection is shown in **Table 7a**. This represents very poor removal of nitrogen. In order to increase the bath depth for the other heats, the shell design was changed as shown in **Figure 4b**. A 'Y' shape was chosen instead of the previous 'U' shape and up to 8 cm bath depth was achieved for 15 kg heat.

A good removal of nitrogen was observed as shown in **Table 7b** when the bath depth was higher (Figure 4b). Therefore, the higher the bath depth the better is the removal of nitrogen. The determination of the optimum bath depth or lance depth was not possible, because it was difficult to increase further. In actual industrial furnaces, a higher bath depth could be achieved and hence the optimum lance depth may be determined to get better results. Anghelina et al. [23] have reported similar results in conducting large scale experiments with 0.5, 0.3 and 0.1 m bath depth.

Addition level of DRI fines. Metal samples were taken at different time interval during the injection and nitrogen content was analysed. For example three plots are shown in **Figure 5**. One is for medium carbon steel (0.66%) and the other two are for high carbon steel (0.86% and 1.2%). The trend of nitrogen removal is nearly the same in all the cases, yet for high carbon steel the requirement of DRI fines is less for all levels of nitrogen. Initially the rate of removal is higher than that at lower nitrogen level in steel with constant rate of DRI fines addition. Therefore, at lower level of nitrogen in steel, more DRI fines injection is needed for nitrogen removal. The equation (8) is developed from basic thermodynamic relations [27] :

$$w / W = \{(N_i - N_f)\,(K_1^2 - f_N^2 N_f^2)\}/38.9 f_N^2 N_f^2 \qquad (8)$$

where N_i and N_f are the initial and final nitrogen content, f_N is the activity coefficient of nitrogen, w and W are weight of FeO in DRI fines and weight of steel respectively.

It indicates the percentage of DRI fines needed for removal of nitrogen to a particular level. Weight of DRI fines needed for removal of nitrogen up to different levels for 15 kg steel is calculated from equation (8) where the carbon content and other alloying elements are considered the same as in experiment No. 6 (Table 5) and plotted in **Figure 6**. The experimental curve and (as per experiment No. 6) the theoretical curve show the same trend of nitrogen removal, which is also supported by Anghelina et al. [23]. The amount of DRI fines needed in the experiments is higher than in theory. This is because of fines loss with flue gas and unreacted FeO in DRI which comes to the slag phase during experimentation.

Theoretically Figure 6 shows a heavy amount of DRI fines is needed for removal of nitrogen below 30 ppm. Practically, as there is a coherent effect of CO bubbles formed by DRI fines and injected Ar gas bubbles, the removal below 30ppm may be possible. However, the bath depth has to be increased sufficiently.

Compositions of product. Oxygen in final steel is varying from around 40-100 ppm, which is within tolerable limit for all the heats as shown in **Table 5 and 6**. Both S and P are well within the tolerable limit (0.03%) except one where sulphur is a little on the higher side. Si and Mn both have been reduced slightly. Si in final product is varying from 0.1 to 0.22 % whereas in scrap (charge materials) it was 0.3%. Mn in final product is varying from 0.2 to 0.28 % whereas in scrap it was 0.4%. This may be due to dilution by DRI fines injection and due to oxidation of Si and Mn in presence of FeO in DRI.

Inclusion level. The microstructure of the final product has been observed in an optical microscope (**Figure 7a and 7b**). The microstructure after etching shows ferrite and pearlite, no inclusion is visible, whereas before etching some minor inclusions are observed.

Yield. In all the cases the metallic yield has been increased. In case of only DRI fines injection the yield has increased to 14 % (**Table 5 and 6**). By mass balance calculation it has been seen that more than 85% of DRI contributes to increase the yield. In case of DRI fines charging followed by iron ore addition the yield has increased to 20.6%. A mass balance shows that 75% of iron ore has been reduced and the rest of the amount may have been retained in slag.

Power consumption. The power consumed at different stages of melting has been measured by a kWh- meter fixed at the panel. The actual and theoretically calculated values of power consumption are shown in **Table 8**. There is a big difference in power consumed during melting. This may be due to the heat loss resulting from radiation and absorption by lining materials.

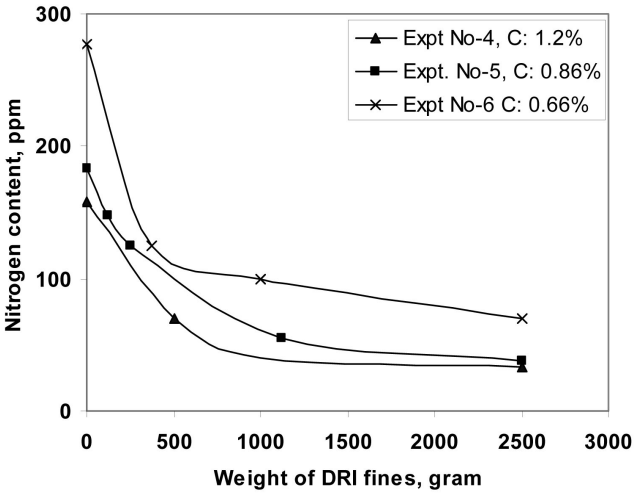

Figure 5. Removal of nitrogen with addition of DRI fines.

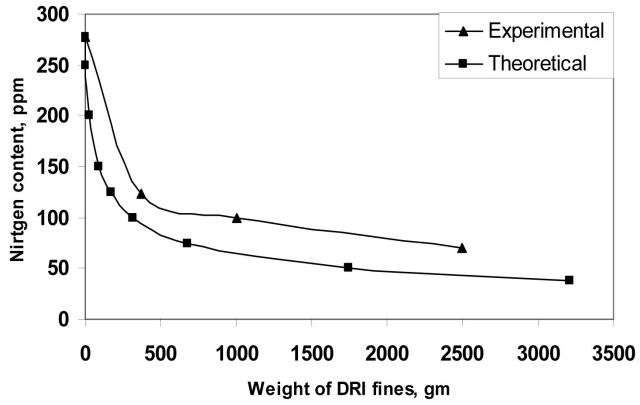

Figure 6. Comparison of experimental versus theoretical curves for nitrogen removal due to DRI fines injection in 0.66% C steel at 1600°C for 15 kg heats.

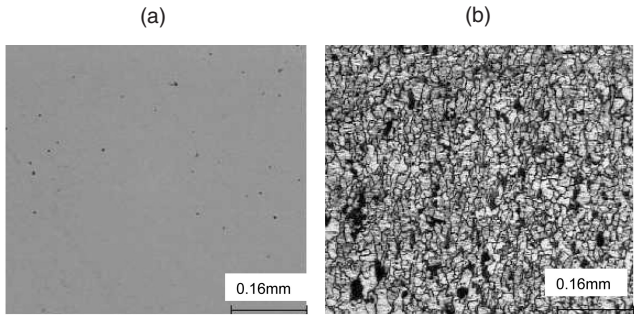

Figure 7. Microstructure of cast steel after nitrogen removal for detection of inclusions. (a) Before etching. (b) After etching (2% Nital).

Table 8. Energy consumption in kWh for 15 kg heats.

	Actual	Calculated
For melting	25	6.01
For Injection	4	2.05
For Iron ore addition	9	1.90

It may be summarized that nitrogen removal is possible to a great extent through DRI fines injection into the steel bath. The problem faced on DRI lump charging (CMP study) at North Star Steel [19] (i.e. CO gas evolves at the surface of the steel bath and CO bubbles do not reach into the bath) may be overcome by injecting DRI fines deep in to the bath. Nitrogen removal through this process depends upon carbon content of the melt and bath depth. The carbon boosts the reaction (1) and a minimum bath depth is required to reduce the fines loss during injection. When residual nitrogen in steel is low, the nitrogen removal rate is also slow, therefore, to obtain a very low nitrogen containing steel, a large amount of DRI fines injection is needed. With the adapted injection process of nitrogen removal, neither the basic composition of steel was changed nor any additional inclusion observed. The metallic yield increases simultaneously with removal of nitrogen, where DRI fines were introduced directly into the EAF. In plant practice a higher bath depth is available and hence the loss of DRI fines through off-gas will be lower and the distribution of DRI fines will be better. Therefore, DRI fines injection is expected to be a good tool for nitrogen removal if bath carbon is high. Steel production through the electric arc furnace- mini blast furnace route consumes hot metal (4% C) up to 60% and is operated with high carbon level and may benefit from adopting this technique on exploring the techno-economic feasibility.

Conclusions

For high carbon steel nitrogen removal is possible to a very low level (around 30ppm).

Steel with low carbon and low nitrogen content can be produced by injection of DRI fines into high carbon bath followed by iron ore addition for removal of carbon.

It is expected that DRI injection can show better results with increased bath depth, which normally prevails in industrial operation.

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